

**PROSTHETIC HIP JOINT HAVING A POLYCRYSTALLINE DIAMOND
ARTICULATION SURFACE AND A PLURALITY OF SUBSTRATE LAYERS**

VI. Claims

We claim:

1. A prosthetic hip joint comprising:
 - an acetabular cup including a sintered polycrystalline diamond compact,
 - a substrate located on said acetabular cup polycrystalline diamond compact,
 - an acetabular cup diamond table sintered to said acetabular cup substrate on said acetabular cup polycrystalline diamond compact,
 - acetabular cup solvent-catalyst metal located in said acetabular cup diamond table,
 - a gradient transition zone between said acetabular cup substrate and said acetabular cup diamond table in said acetabular cup polycrystalline diamond compact, said acetabular cup gradient transition zone having a substrate side and a diamond table side, said acetabular cup gradient transition zone having both acetabular cup solvent-catalyst metal and diamond therein, and said acetabular cup gradient transition zone exhibiting a transition of ratios of percentage content of acetabular cup solvent-catalyst metal to diamond from one side of said gradient transition zone to another such that at a first point in said acetabular cup gradient transition zone near said substrate side, the ratio of percentage content of acetabular cup solvent-catalyst metal to diamond is greater than it is at a second point in said acetabular cup gradient transition zone closer to said diamond side than said first point,

chemical bonds between said acetabular cup diamond table and said acetabular cup substrate which tend to secure said diamond table to said substrate,

an acetabular cup load bearing and articulation surface on said polycrystalline diamond compact, said acetabular cup load bearing and articulation surface including polycrystalline diamond, said acetabular cup load bearing and articulation surface being formed to present a shape that is at least partially concave spherical and against which a femoral head may articulate,

a femoral head for articulation against said acetabular cup load bearing and articulation surface, said femoral head including a sintered polycrystalline diamond compact,

a first femoral head substrate layer located on said femoral head polycrystalline diamond compact,

a second femoral head substrate layer located on said femoral head polycrystalline diamond compact, said second substrate being in proximity to said first substrate,

a femoral head diamond table sintered to said first femoral head substrate layer on said femoral head polycrystalline diamond compact,

femoral head solvent-catalyst metal located in said femoral head diamond table,

a gradient transition zone between said first femoral head substrate layer and said femoral head diamond table in said femoral head polycrystalline diamond compact, said femoral head gradient transition zone having a substrate side and a diamond table side, said femoral head gradient transition zone having both femoral head solvent-catalyst metal and diamond therein, and said femoral head gradient transition zone exhibiting a transition of ratios of percentage content of femoral head solvent-catalyst metal to

diamond from one side of said gradient transition zone to another such that at a first point in said femoral head gradient transition zone near said substrate side, the ratio of percentage content of femoral head solvent-catalyst metal to diamond is greater than it is at a second point in said femoral head gradient transition zone closer to said diamond side than said first point,

chemical bonds between said femoral head diamond table and said first femoral head substrate layer which tend to secure said diamond table to said substrate first femoral head substrate, and

a femoral head load bearing and articulation surface on said polycrystalline diamond compact, said femoral head load bearing and articulation surface including polycrystalline diamond, said femoral head load bearing and articulation surface being formed to present a shape that is at least partially convex spherical.

2. A joint as recited in claim 1 wherein said second femoral head substrate layer has a convex spherical outer surface.

3. A joint as recited in claim 1 wherein said second femoral head substrate layer is at least partially spherical.

4. A joint as recited in claim 1 wherein said first femoral head substrate layer comprises at least two partially spherical shells which when assembled provide an interior receptacle for said second femoral head substrate layer.

5. A joint as recited in claim 4 wherein said second femoral head substrate layer is a sphere.

6. A joint as recited in claim 1 wherein said first femoral head substrate layer includes a spherical portion with a passage to its center; wherein said second femoral

head substrate layer includes a sphere located in said first femoral head substrate layer center; and further comprising a plug substrate material placed in said passage.

7. A joint as recited in claim 1 wherein said first femoral head substrate layer includes a metal alloy containing cobalt-chrome and wherein said second femoral head substrate layer includes a metal alloy containing titanium.

8. A joint as recited in claim 1 wherein at least one of said femoral head substrate layers includes a plurality of metals.

9. A joint as recited in claim 1 wherein at least one of said femoral head substrate layers includes at least one metal selected from the group consisting of titanium, aluminum, vanadium, molybdenum, hafnium, nitinol, cobalt, chrome, molybdenum, tungsten, cemented tungsten carbide, cemented chrome carbide, fused silicon carbide, nickel, tantalum, niobium, zirconium, hafnium, tungsten, and stainless steel.

10. A joint as recited in claim 1 wherein at least one of said femoral head substrate layers includes CoCr as a solvent-catalyst metal.

11. A joint as recited in claim 1 wherein said femoral head substrate layers are made from two different materials.

12. A joint as recited in claim 1 wherein said femoral head substrate layers are made from at least two different metal alloys.

13. A joint as recited in claim 1 wherein said femoral head substrate layers are made at least two different cemented carbides.

14. A joint as recited in claim 1 wherein diamond in said femoral head polycrystalline diamond compact has a coefficient of thermal expansion CTE_{Cd} , wherein said first femoral head substrate layer has a coefficient of thermal expansion CTE_{sub1} ,

wherein said second femoral head substrate layer has a coefficient of thermal expansion CTE_{sub2} , wherein CTE_{Cd} is not equal to CTE_{sub1} , wherein CTE_{Cd} is not equal to CTE_{sub2} , and wherein CTE_{sub1} is not equal to CTE_{sub2} .

15. A joint as recited in claim 1 wherein diamond in said femoral head polycrystalline diamond compact has a modulus M_{Cd} , wherein said first femoral head substrate layer has a modulus M_{sub1} , wherein said second femoral head substrate layer has a modulus M_{sub2} , wherein M_{Cd} is not equal to M_{sub1} , wherein M_{Cd} is not equal to M_{sub2} , and wherein M_{sub1} is not equal to M_{sub2} .

16. A joint as recited in claim 1 further comprising a mechanical grip between said femoral head diamond table and said first femoral head substrate layer, said mechanical grip tending to secure said diamond table to said first femoral head substrate layer.

17. A joint as recited in claim 4 further comprising topographical features on said first femoral head substrate layer which tend to enhance said mechanical grip.

18. A joint as recited in claim 1 further comprising substrate metal located in said femoral head diamond table.

19. A joint as recited in claim 1 further comprising a residual stress field in said femoral head cup polycrystalline diamond compact that tends to enhance the strength of said femoral head polycrystalline diamond compact.

20. A joint as recited in claim 1 wherein said second femoral head substrate layer has a barrier layer present on at least a portion of its exterior.

21. A joint as recited in claim 20 wherein said barrier layer includes a material selected from the group consisting of tantalum, zirconium, molybdenum

and tungsten.

22. A joint as recited in claim 1 further comprising an oxidation layer present on at least a portion of the exterior surface of said second femoral head substrate layer.

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23. A joint as recited in claim 1 wherein said first femoral head substrate layer has surface topographical features for establishing a firm bond with said femoral head diamond table.

24. A prosthetic hip joint comprising:
an acetabular cup,
an acetabular cup load bearing and articulation surface,
a femoral head,
a femoral head load bearing and articulation surface for articulation against said acetabular cup load bearing and articulation surface,
a polycrystalline diamond compact located in at least one of said acetabular cup and said femoral head,,
a first substrate layer located in said polycrystalline diamond compact,
a second substrate layer located in said polycrystalline diamond compact, and
a diamond table attached to said first substrate layer;
wherein said diamond table forms at least a portion of one of said load bearing and articulation surfaces.

25. A joint as recited in claim 24 wherein said first substrate layer has a generally convex spherical outer surface.

26. A joint as recited in claim 25 wherein said first substrate layer has a hole to its approximate center.

27 ~~26~~. A joint as recited in claim 2⁶~~6~~ wherein said second substrate layer is located in said hole.

28. A joint as recited in claim 2⁷~~6~~ wherein said second substrate layer is at least partially spherical.

29. A joint as recited in claim 28 further comprising a plug located in said first substrate layer hole.

30. A joint as recited in claim 29 wherein said plug is formed from a substrate material; and wherein said plug is shaped to closely abut said second substrate layer.

31. A joint as recited in claim 23 wherein said first substrate layer comprises two half shells which, when assembled together, form a receptacle therebetween.

32. A joint as recited in claim 31 wherein said second substrate layer is present in said receptacle.

33. A joint as recited in claim 32 wherein said second substrate layer is convex spherical in shape.

34. A joint as recited in claim 2⁴~~3~~ wherein one of said first substrate layer and said second substrate layer comprises titanium and the other of said layers comprises cobalt-chrome.

35. A joint as recited in claim 2⁴~~3~~ wherein at least one of said substrate layers includes at least one metal selected from the group consisting of titanium, aluminum, vanadium, molybdenum, hafnium, nitinol, cobalt, chrome, molybdenum, tungsten, cemented tungsten carbide, cemented chrome carbide, fused silicon carbide, nickel, tantalum, niobium, zirconium, hafnium, tungsten, and stainless steel.

36. A joint as recited in claim 2⁴~~3~~ wherein at least one of said solvent-catalyst

metals is CoCr.

37 ~~38~~. A joint as recited in claim 2⁴~~3~~ wherein said substrate layers are made from two different materials.

38 ~~39~~. A joint as recited in claim 2⁴~~3~~ wherein said femoral head substrate layers are made from at least two different metal alloys.

39 ~~40~~. A joint as recited in claim 2⁴~~3~~ wherein said femoral head substrate layers are made at least two different cemented carbides.

40 ~~41~~. A joint as recited in claim 2⁴~~3~~ wherein diamond in said polycrystalline diamond compact has a coefficient of thermal expansion CTE_{Cd} , wherein said first substrate layer has a coefficient of thermal expansion CTE_{sub1} , wherein said second substrate layer has a coefficient of thermal expansion CTE_{sub2} , wherein CTE_{Cd} is not equal to CTE_{sub1} , wherein CTE_{Cd} is not equal to CTE_{sub2} , and wherein CTE_{sub1} is not equal to CTE_{sub2} .

41 ~~42~~. A joint as recited in claim 2⁴~~3~~ wherein diamond in said polycrystalline diamond compact has a modulus M_{Cd} , wherein said first substrate layer has a modulus M_{sub1} , wherein said second substrate layer has a modulus M_{sub2} , wherein M_{Cd} is not equal to M_{sub1} , wherein M_{Cd} is not equal to M_{sub2} , and wherein M_{sub1} is not equal to M_{sub2} .

42 ~~43~~. A joint as recited in claim 2⁴~~3~~ further comprising a mechanical grip between diamond table and said first substrate layer, said mechanical grip tending to secure said diamond table to said first femoral head substrate layer.

43 ~~44~~. A joint as recited in claim 4²~~3~~ further comprising topographical features on said first substrate layer which tend to enhance said mechanical grip.

44 ~~45~~. A joint as recited in claim 2⁴~~3~~ further comprising a residual stress field in

said polycrystalline diamond compact that tends to enhance the strength of said polycrystalline diamond compact.

45 ~~46~~. A joint as recited in claim 2⁴~~3~~ wherein said second femoral head substrate layer has a barrier layer present on at least a portion of its exterior.

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46 ~~47~~. A joint as recited in claim 4⁵~~6~~ wherein said barrier layer is selected from the group consisting of tantalum, molybdenum, zirconium, molybdenum, and tungsten.

47 ~~48~~. A joint as recited in claim 4⁶~~7~~ wherein said tantalum barrier layer has a thickness of between about 0.0002 to about 0.010 inches.

48 ~~49~~. A joint as recited in claim 2⁴~~3~~ further comprising an oxidation layer present on at least a portion of the exterior surface of at least one of said substrate layers.

49 ~~50~~. A joint as recited in claim 2⁴~~3~~ further comprising an alpha coat on at least a portion of the exterior surface of at least one substrate layer.

50 ~~51~~. A prosthetic joint comprising:

- a first substrate layer,
- a second substrate layer adjacent said first substrate layer,
- a substrate material that includes a solvent-catalyst metal present in at least said first substrate layer,
- a diamond layer sintered to said first substrate layer,
- a zone between said first substrate layer substrate and said diamond layer that has a composition gradient of decreasing solvent-catalyst metal content across said zone,

chemical bonds in said zone, said chemical bonds including diamond-to-diamond bonds in said diamond table, diamond-to-metal bonds in said gradient transition zone, and metal-to-metal bonds in said solvent-catalyst metal.

a mechanical grip between said diamond layer and said first substrate layer which tends to secure said diamond layer to said first substrate layer,

interstitial spaces in said diamond layer,

solvent-catalyst metal present in said interstitial spaces, and

a non-planar load bearing and articulation surface formed by said diamond layer.

51 ~~52~~. A joint as recited in claim ⁵⁰~~50~~ wherein sintered diamond in said diamond layer has a coefficient of thermal expansion CTE_{Cd} , and wherein said first substrate layer substrate has a coefficient of thermal expansion CTE_{sub} , and wherein CTE_{Cd} is not equal to CTE_{sub} .

52 ~~53~~. A joint as recited in claim ⁵⁰~~51~~ wherein said sintered diamond in said diamond layer has a modulus M_{Cd} , and wherein said first substrate layer has a modulus M_{sub} , and wherein M_{Cd} is not equal to M_{sub} .

53 ~~54~~. A joint as recited in claim ⁵⁰~~50~~ further comprising a residual stress field that tends to enhance the strength of attachment of said diamond layer to said first substrate layer.

54 ~~55~~. A joint as recited in claim ⁵⁰~~50~~ further comprising substrate surface topographical features on said first substrate layer.

55 ~~56~~. A joint as recited in claim ⁵⁰~~50~~ wherein at least one of said substrate layers includes at least one metal selected from the group consisting of titanium, aluminum, vanadium, molybdenum, hafnium, nitinol, cobalt, chrome, molybdenum, tungsten, cemented tungsten carbide, cemented chrome carbide, fused silicon carbide, nickel, tantalum, niobium, zirconium, hafnium, tungsten, and stainless steel.

56 ~~57~~. A joint as recited in claim ~~51~~⁵⁰ wherein diamond layer comprises diamond feedstock that has diamond particles that have a dimension in the range of less than about 1 nanometer to more than about 100 microns.

57 ~~58~~. A joint as recited in claim ~~51~~⁵⁰ wherein said diamond load bearing and articulation surfaces is a continuous diamond surface.

58 ~~59~~. A joint as recited in claim ~~51~~⁵⁰ wherein said diamond load bearing and articulation surface is a discontinuous diamond surface.

59 ~~60~~. A joint as recited in claim ~~51~~⁵⁰ wherein said diamond load bearing and articulation surface is a segmented diamond surface.

60 ~~61~~. A joint as recited in claim ~~51~~⁵⁰ wherein a lip is present on said substrate in order to interlock said diamond layer to said substrate.

61 ~~62~~. A joint as recited in claim ~~51~~⁵⁰ further comprising CoCr solvent-catalyst metal in said diamond table interstitial spaces.

62 ~~63~~. A joint as recited in claim ~~51~~⁵⁰ further comprising a continuous gradient in said diamond layer.

63 ~~64~~. A joint as recited in claim ~~51~~⁵⁰ further comprising an incremental gradient in said diamond layer.

64 ~~65~~. A joint as recited in claim ~~64~~³ wherein said incremental gradient includes a plurality of strata in said diamond layer, a first of said strata having characteristics which differ from those of a second strata.

65 ~~66~~. A joint as recited in claim ~~65~~⁴ wherein said differing characteristics of said strata are selected from the group consisting of diamond particle size, diamond particle distribution, and solvent-catalyst metal content.

66 ~~67~~. A joint as recited in claim ~~51~~⁵⁰ further comprising an interface gradient.

67 ~~68~~. A joint as recited in claim ~~51~~⁵⁰ wherein said diamond layer has a thickness of from less than about 1 micron to more than about 3000 microns.

68 ~~69~~. A joint comprising:

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a substrate including at least two distinct substrate layers, at least two of said substrate layers having metal content different from each other,
a diamond layer sintered to said substrate,
interstitial spaces located in said diamond layer,
solvent-catalyst metal located in said interstitial spaces,
a zone that includes both sintered diamond and substrate, said zone having a composition gradient of solvent-catalyst metal content to diamond content, said gradient being selected from the group consisting of interface gradient, continuous gradient and incremental gradient,

chemical bonds in the joint, said chemical bonds including diamond-to-diamond bonds in said diamond layer, diamond-to-metal bonds in said zone, and metal-to-metal bonds in said solvent-catalyst metal,

a mechanical grip between said diamond layer and said substrate which tends to secure said diamond layer to said substrate, and

a non-planar load bearing and articulation surface formed by said diamond layer.

69 ~~70~~. A joint as recited in claim ~~69~~⁸ further comprising a lip of substrate material which serves to hold said diamond layer in place adjacent said substrate.

70 ~~71~~. A joint as recited in claim ~~69~~⁸ further comprising a dovetailed interlock between said diamond table and said substrate.

~~12~~ 73. A joint as recited in claim ~~69~~ wherein at least some of said bonds are sp³ carbon bonds.

73 ~~74~~. A joint as recited in claim 6~~9~~ wherein said diamond table includes a plurality of strata such that a first of said strata having characteristics which differ from those of a second strata.

74 75. A joint as recited in claim 74 wherein said differing characteristics are selected from the group consisting of diamond particle size, diamond particle distribution, and solvent-catalyst metal content.

75 ~~76.~~ A joint as recited in claim 69³ wherein said diamond table is formed using CoCr as
a solvent-catalyst metal.

76 ~~77~~ A joint as recited in claim ~~69~~⁸ further comprising a plurality of diamond strata in said zone.

~~77~~ ⁸78. A joint as recited in claim 6~~9~~ wherein said diamond table presents a non-planar diamond load bearing and articulation surface.

76 ~~79~~. A joint as recited in claim ~~69~~⁸ wherein said interstitial spaces are filled with a metal.

79 ~~80~~. A joint as recited in claim 6⁸~~9~~ wherein said interstitial spaces are filled with solvent-catalyst metal.

80 ~~81.~~ A joint as recited in claim 6⁸ further comprising a transition zone in said substrate.

81 82. A joint for use in a prosthetic joint, the articulation surface comprising:

a load bearing and articulation portion,
a first substrate layer located in said load bearing and articulation portion,
a second substrate layer located in said load bearing and articulation portion,
a volume of superhard material located on said load bearing and articulation
portion, and

a superhard articulation surface formed by at least a portion of said volume of
superhard material, said articulation surface being formed to permit low-friction
articulation in a joint, and said superhard articulation surface forming at least a portion of
said load bearing and articulation surface.

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82 ~~83~~. A joint as recited in claim ~~81~~ wherein said superhard material is selected from the
group consisting of diamond, cubic boron nitride and wurzitic boron nitride.

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34. A joint as recited in claim ~~82~~ wherein said superhard material has a Knoop
hardness of at least about 4000.